

Summertime tropospheric ozone columns from Aura OMI/MLS measurements versus regional model results over the United States

P. Jing, D. M. Cunnold, Y. Choi and Y. Wang (Paper 2006GL026473)
School of Earth and Atmospheric Sciences, Georgia Institute of Technology, Atlanta, GA, 30332

1. Motivation and goals

Global monitoring of tropospheric ozone is needed in order to accurately understand and assess its impacts on tropospheric photochemistry and global radiative forcing. Among the current techniques of obtaining the tropospheric ozone column (TOC), satellite-born remote sensing instruments are the most efficient way to obtain the global distribution of tropospheric ozone.

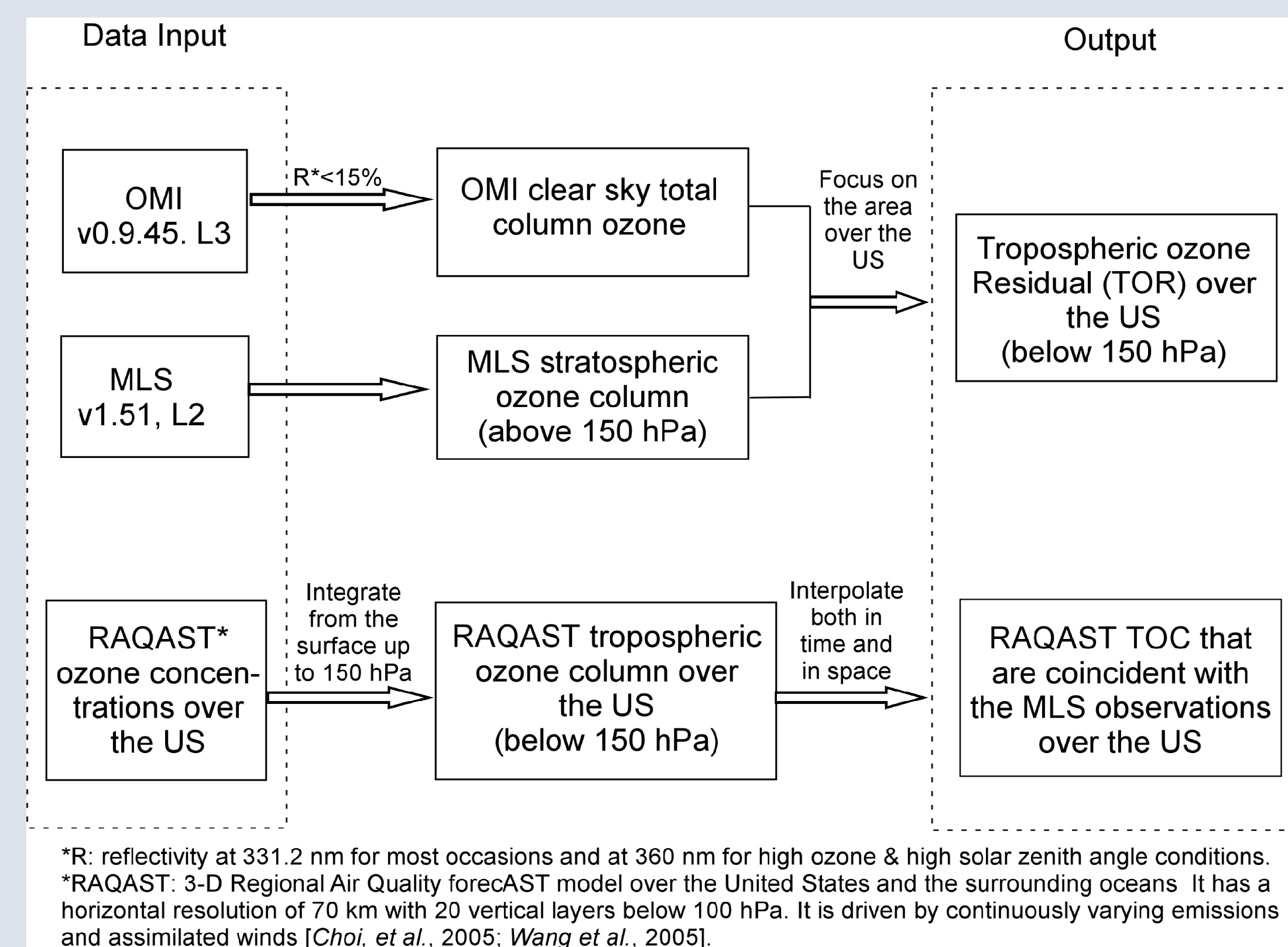
The main objectives of this study are: 1) to use Ozone Monitoring Instrument (OMI) and Microwave Limb Sounder (MLS) measurements on NASA's Aura Mission to derive TOC; and 2) to interpret the variations in the derived TOC using a regional transport and chemistry model over the United States, i.e., the Regional Air Quality Forecast (RAQAST) model.

2. Data and approach

The tropopause, which is generally defined by a lapse rate of less than $2^{\circ}\text{K}/\text{km}$, was generally located above the 150 hPa level between 40°N and 30°S in June-August 2005. The major area for this study is between 25° and 40°N over the United States, over which the atmosphere below 150 hPa is almost entirely tropospheric.

MLS ozone profiles agree well (within 10%) with ozonesonde and other satellite profiles above 147 hPa (e.g. Froidevaux et al., 2006) but they have tended to be high below that. Therefore this study used the 147 hPa to approximate the location of the tropopause.

The 'stratospheric' ozone columns above 147 hPa are derived from MLS profiles. The clear-sky 'tropospheric' column ozone below 147 hPa is obtained by taking the residual between the OMI total column ozone and the MLS 'stratospheric' ozone column. Here linear interpolation of level 3 OMI columns from the four 1° latitude \times 1.25° longitude grid boxes closest to, and measured within approximately 7 minutes of, the MLS measurements are used. Only MLS data having reflectivities less than 0.15 are used (using reflectivities less than 0.30 yielded only about 20% more profiles)



The RAQAST model forecasts the concentrations of ozone and its precursors over the United States and the near coast ocean areas on 23 vertical levels from the surface to 10 hPa with a horizontal resolution of about 70 km (updated version of Choi et al., 2005). Meteorological fields are from MM5 based on NCEP reanalysis data plus rawinsondes. Daily chemical boundary conditions and emissions are from GEOS-CHEM simulations (Bey et al., 2001).

3. TCOs (below 147 hPa)

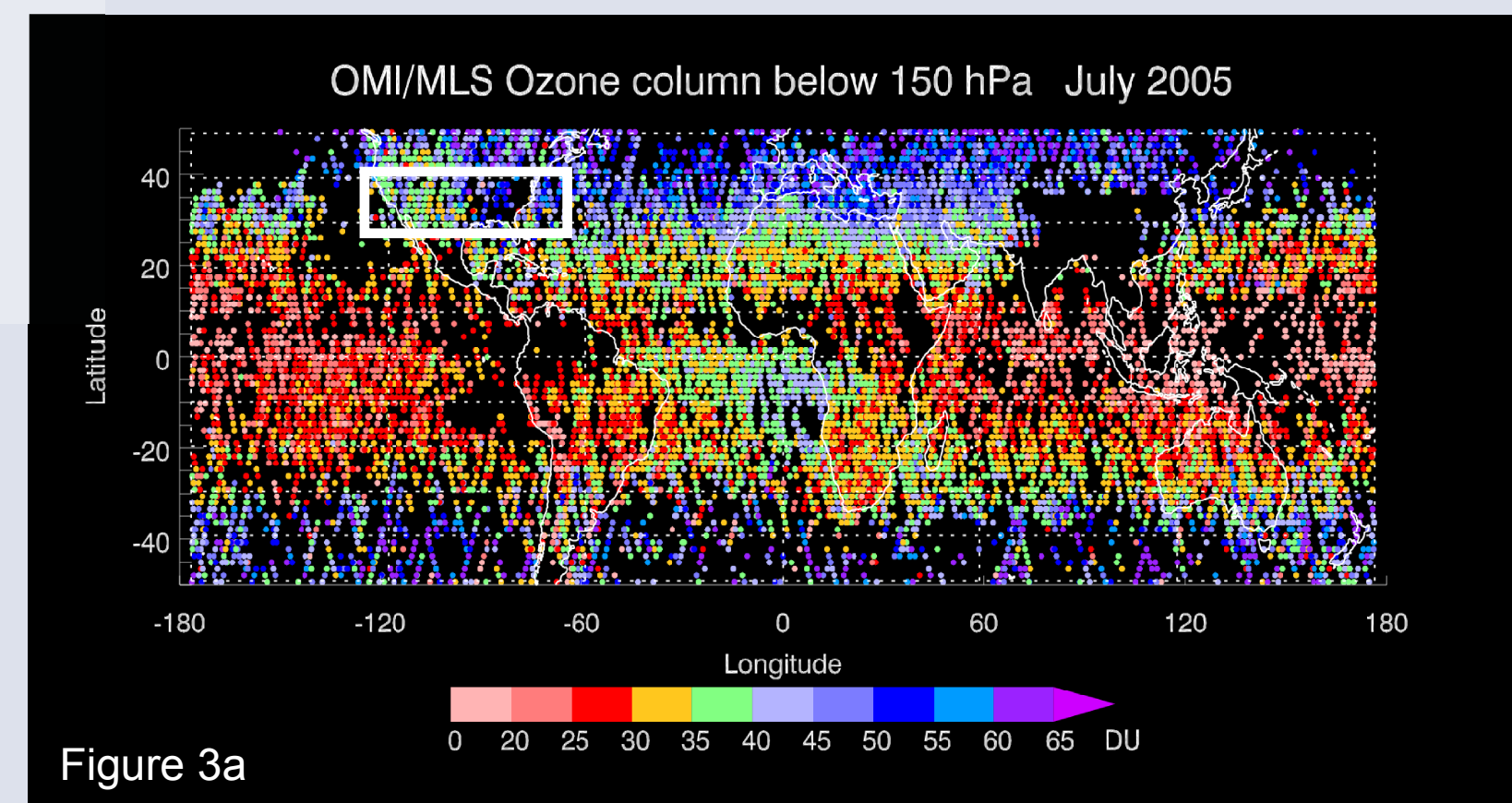


Figure 1. Estimated clear-sky OMI/MLS tropospheric ozone residuals (TOR) in Dobson Unit (DU) in July 2005. The area over the US and the surrounding ocean areas that will be address in this study is highlighted by the white box.

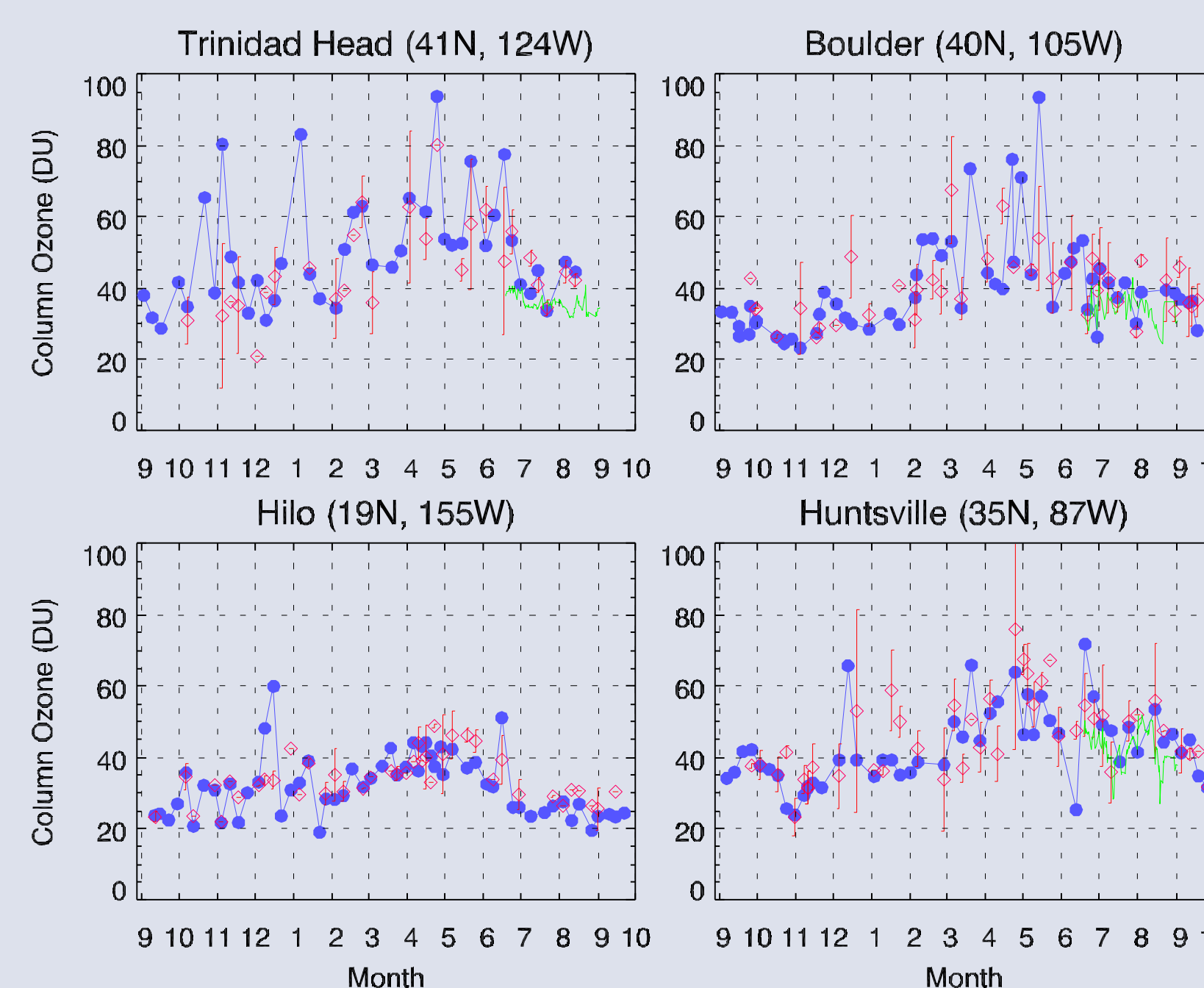


Figure 3. Column ozone BELOW 147 hPa from ozonesonde measurements (blue dots) and from OMI/MLS residuals (red diamonds) over four USA stations from September 2004 to September 2005. Error bars, representing one standard deviation, are given for OMI/MLS column ozone when more than three OMI/MLS residuals meet the coincidence criteria. The coincidence criteria are: ± 24 hours in time, $\pm 10^{\circ}$ in longitude, and $\pm 5^{\circ}$ in latitude around ozonesonde measurement locations. The green solid line represents the daily average RAQAST assimilations over the stations in summer 2005

4. Comparisons vs. RAQAST predictions

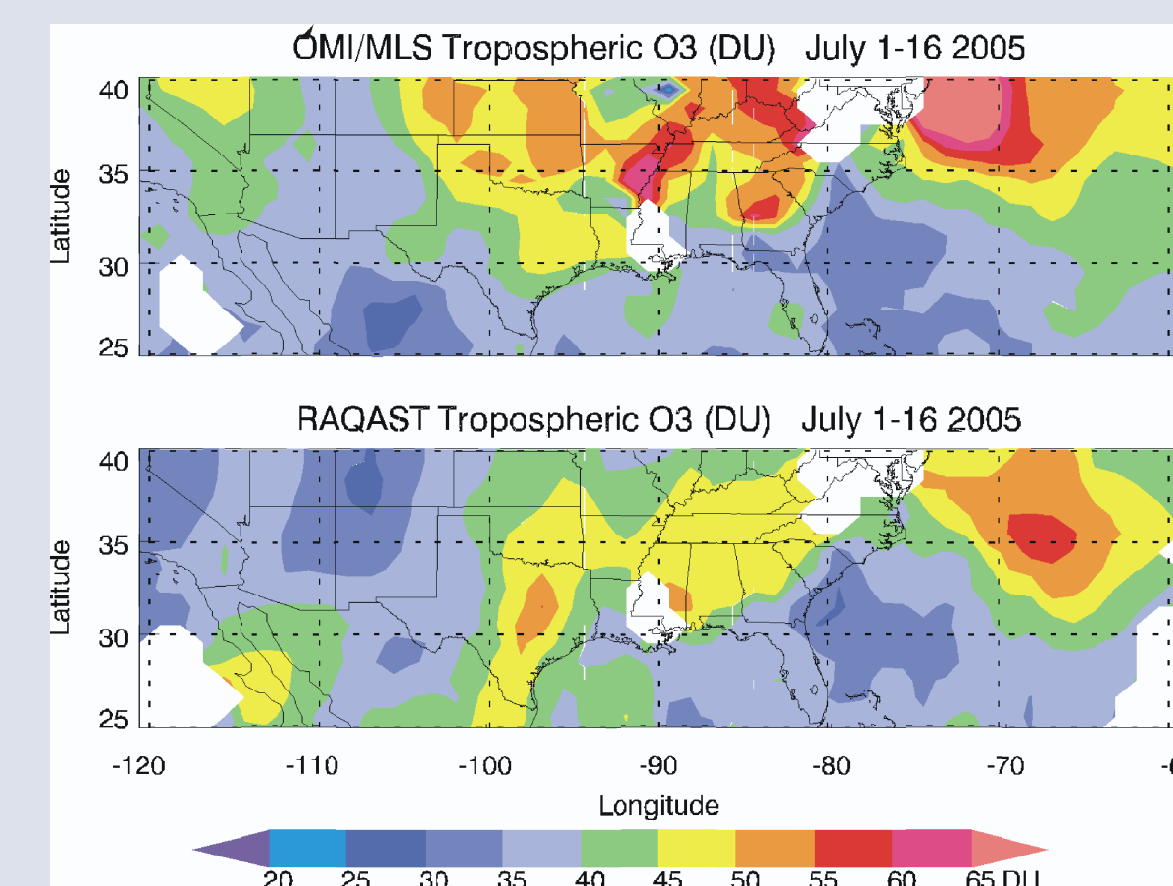
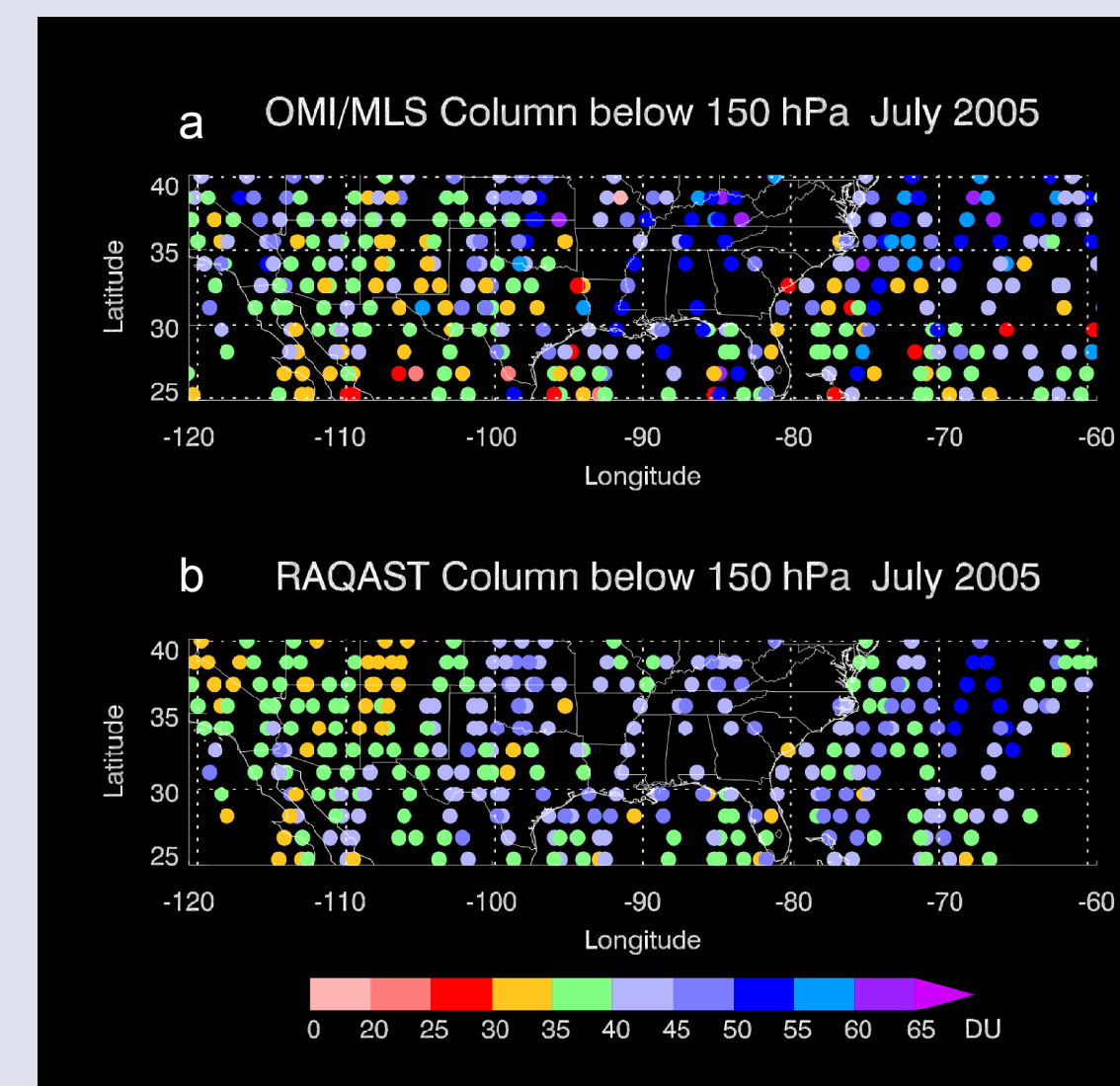


Figure 4. Time-averaged 'tropospheric' ozone columns (in DU) below 147 hPa for July 1-16, 2005 derived from OMI/MLS residuals (top) and RAQAST modeling results (bottom). Gridding has been based on a Barnes interpolation scheme*.

[*Barnes interpolation scheme: This scheme interpolates to a target point by taking a weighted average of points surrounding the target point within an influence distance D ($D=250$ km in this study). The weight of each point is $\exp(-d/D)$, in which d is the distance of this point to the target point.]

Both the semi-monthly clear-sky OMI/MLS and RAQAST TCO maps over the USA in summer 2005 show maximum ozone regions over the northwestern Atlantic and over most of the eastern and mid-western states (Figure 4). The high TCO levels over the southeastern states are associated with high RAQAST near-surface (here defined as the column below 750 hPa or ~ 2 km altitude) ozone levels and high NOx concentrations (not shown). This suggests that the clear-sky OMI/MLS TORs are able to represent the spatial distribution of monthly summertime tropospheric ozone columns, and that the high TOR regions over the US are associated with surface ozone photochemistry.



Focus over the US

Figure 2. a) A subset (in the white box) of Figure 1 over the US. b) RAQAST tropospheric ozone columns (TOC) that are coincident to the OMI/MLS residuals in a).

Both the sondes and OMI/MLS show the highest column ozone values in April and May. For individual stations from Hilo at lower latitude to Trinidad at higher latitude, the mean bias of the OMI/MLS TCO compared to the sondes ranges from 1.3 to -3.8 DU (or from 4% to -9%) and the rms differences range from 7.0 to 12.8 DU (or from 18% to 23%). **Combining the four stations, the relative bias is +0.3 DU (or +1%), the rms is 10.1 DU (or 2.2%), and the correlation coefficient is 0.67.**

For the summertime comparisons between OMI/MLS TCO and ozonesondes in Figure 3, **the mean bias is +0.8 DU (+2%), RMS is 8.9 DU (23%), and correlation coefficient is 0.73.** The RAQAST assimilated TCOs are also shown to be in good agreement with ozonesondes for summer 2005 (Figure 3), **with a bias of -6.2 \pm 6.5 DU (-12.2 \pm 12.8%) and correlation coefficient of 0.68.**

The effect of assuming the 147 hPa representing the tropopause in summer: At Hilo and Huntsville, the tropopause is usually located at 123 ± 18 hPa, and the actual tropospheric ozone columns are 1.5 ± 2.5 DU more than the column below 147 hPa. For Boulder and Trinidad Head, the tropopause is located at 160 ± 35 hPa, and the tropospheric ozone columns are 5.0 ± 7.0 DU less than the column below 147 hPa.

4. Continue

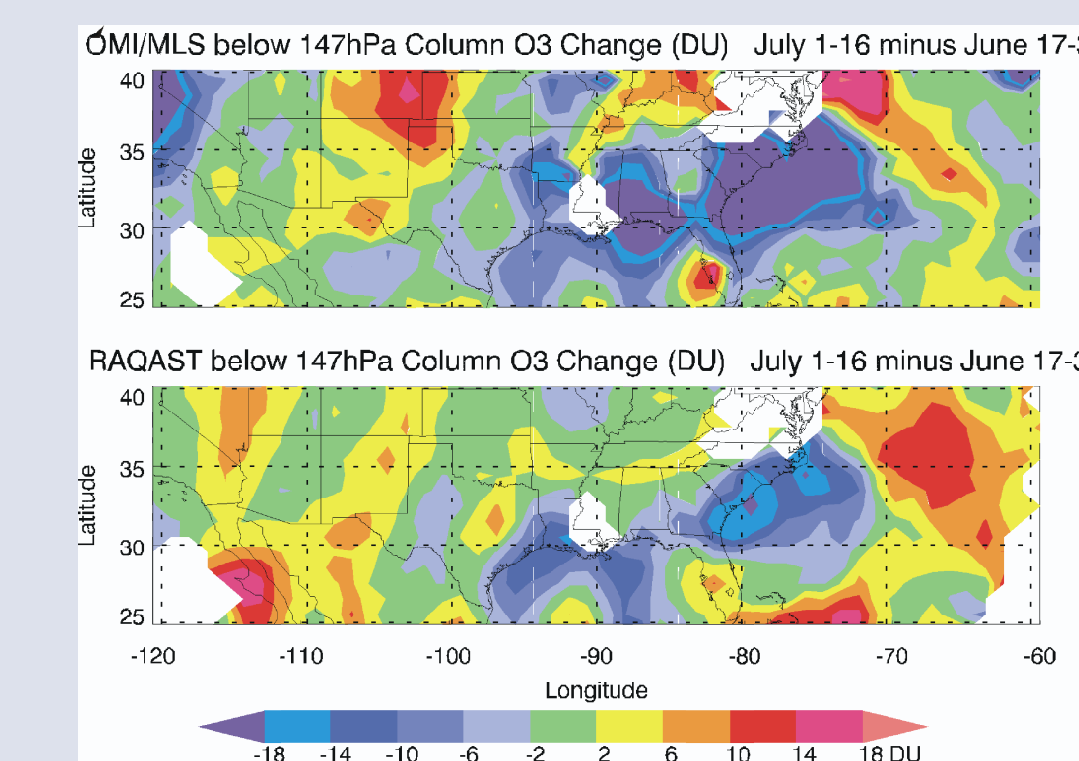


Figure 6. 'Tropospheric' column ozone differences (in DU) between July 1-17 and June 17-30, 2005 from the OMI/MLS residual method (top) and RAQAST model (bottom).

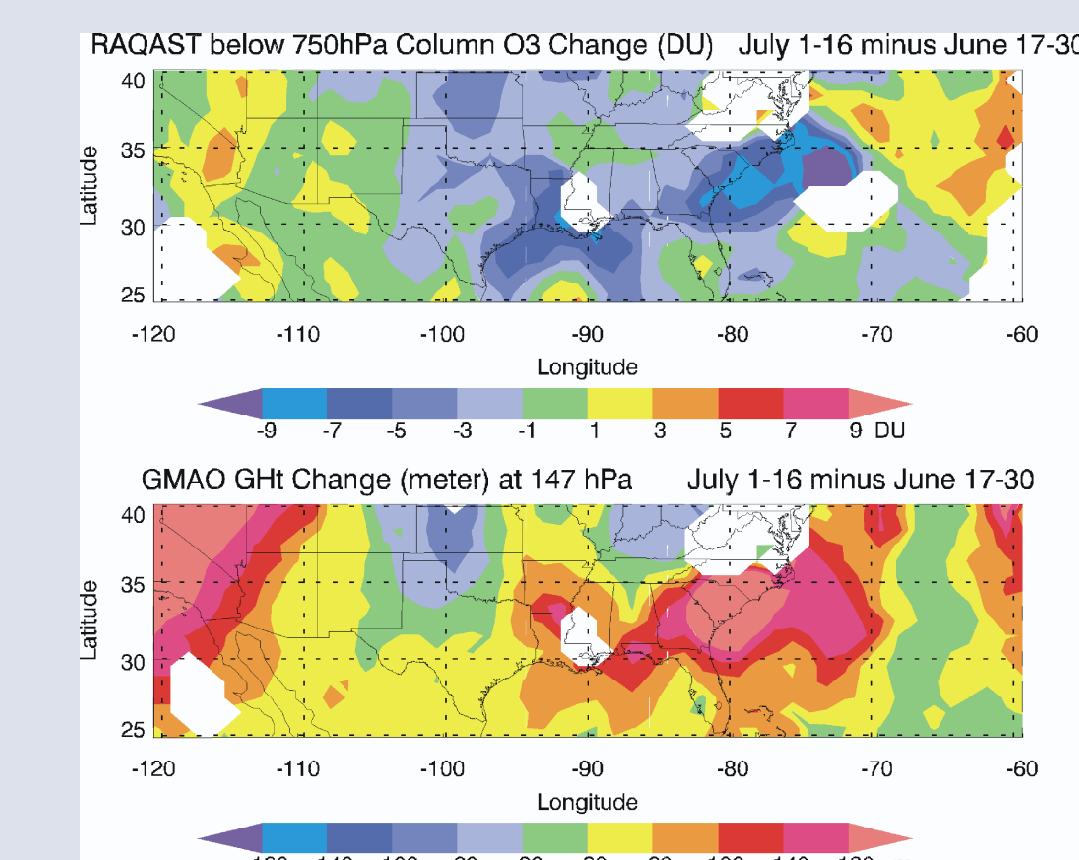


Figure 7. RAQAST ground-to-750 hPa column ozone changes 9in DU (top) and GMAO geopotential height changes (in meters) at 147 hPa (bottom) between July 1-17 and June 17-30, 2005.

The changes from June 17-30 to July 1-16 in the OMI/MLS and RAQAST TCOs show significant decreases (>6 DU) along the southeast coast of the USA and the Gulf of Mexico. Significant increase (>6 DU) are found over the northwestern Atlantic and over the western states (Figure 6). Opposite increasing and decreasing tendencies are found in GMAO (Global Modeling and Assimilation Office) geopotential height changes at 147 hPa pictured below.

At 25° - 35° latitude, the changes in the columns from late June to early July are correlated with ozone changes below 750 hPa ($R\sim 0.6$). However at 35° - 40° latitude, this correlation coefficient is near zero. On the other hand the column changes at 35° - 40° latitude are shown to be anti-correlated with geopotential height changes ($R\sim -0.5$).

A strong trough reaching into the deep south was noted on the geopotential height map at 147 hPa over the southeastern states in late June, but it was not found there in early July. The trough could have brought ozone-rich air into the tropospheric column most likely from higher latitudes through quasi-horizontal advection or from higher altitudes through downward diabatic motions. Two week later, from July 1-16 to July 17-31, both the OMI/MLS and the RAQAST simulations show that the increases and decreases have been mostly reversed, with TCO decreasing over the northwestern Atlantic and over the western states and increasing over the south and east coasts (not shown), and these changes are associated with a reversal of the changes in the geopotential height field at 147 hPa.

5. Summary and discussions

- The OMI/MLS derived "tropospheric" ozone column (here columns below 147 hPa) show good agreement with coincident ozone columns measured between June and August 2005 at four ozonesonde sites in the USA. The overall correlation coefficient is 0.73 and the mean difference is 1 DU with rms differences of 9DU. RAQAST regional chemical and transport model ozone columns compared with three continental ozonesonde sites' measurements show a low bias of 6DU with rms differences of ± 7 DU and a correlation coefficient of 0.68.
- High OMI/MLS tropospheric ozone columns are mostly found in summer over the USA where ozone photochemistry is active in the lower troposphere. However the results also demonstrate that meteorological conditions play an important role in the semi-monthly changes in tropospheric ozone columns at midlatitudes over the USA in summer and that these changes have also been captured by the OMI/MLS observations.

6. References

- Bey, I et al. (2001) Global modeling of tropospheric chemistry with assimilated meteorology: Model description and evaluation, *J. Geophys. Res.*, **106**, 23,073--23,095.
- Choi, Y., Y. Wang, T. Zeng, R. V. Martin, T. P. Kurosu, and K. Chance (2005), Evidence of lightning NOx and convective transport of pollutants in satellite observations over North America, *Geophys. Res. Lett.*, **32**, doi:10.1029/2004GL021436.
- Froidevaux, L. and 27 others (2006), Early validation analyses of atmospheric profiles from EOS MLS on the Aura satellite, *IEEE Transactions on Geosciences and Remote Sensing*, **44** (5), 1106-1121.